Estimating the percentage of adult delta smelt entrained
at the Banks and Tracy Pumping Plants
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Background

Adult delta smelt (smelt) spawn beginning in February or March. Adult spawners are spread throughout their range, from San Pablo Bay to the eastern Delta (Figure 1). Some adults are entrained at the Banks and Tracy Pumping Plants in the southeastern Delta. The Banks Pumping Plant has a 30,000 acre-foot forebay, Clifton Court Forebay, where predation and other mortality occur. The Tracy Pumping Plant has no forebay, but predation and other mortality occur in front of the trash booms and at other locations within the pumping facilities.

At each pumping plant, smelt and other fish are diverted into salvage tanks by louvers. Smelt that are not diverted are exported from the Bay-Delta system and eventually die. Salvaged smelt are counted and measured periodically. The counts are extrapolated to estimate the total number of smelt salvaged each day. This "expanded" count is typically called "salvage."

Most species of fish can actually be salvaged, that is, collected from the salvage tanks, trucked to the western Delta, and released alive. However, delta smelt are too fragile to survive this process. All salvaged smelt typically die. Therefore, for smelt, entrainment equals mortality.

Smelt die after spawning. Soon after they spawn, entrainment of larval and, then, juvenile smelt begins. Because smelt spawn over several weeks, there can be continual salvage of smelt in the winter and spring, first adults, then juveniles of at least 20 mm in length. (Smaller smelt are entrained but are not counted in the salvage tanks.) However, in most years there is little overlap in entrainment of adults and juveniles of length greater than 20 mm. In such years the period separating adult and juvenile salvage can be determined from the salvage length measurements. In years when overlap occurs, length measurements can be used to segregate adults and juveniles.

Estimating entrainment from salvage

Entrainment is routinely estimated from salvage for salmon and striped bass. Screening efficiencies have been estimated for different sizes of these species and for different approach velocities. Knowing salvage (that is, "expanded salvage") and screening efficiency, estimates can be made of the number of fish approaching the screens.

The number approaching the screens is the number that survived prescreen predation. Estimates have been made for prescreen mortality as well. For the Banks Pumping Plant, prescreen mortality for salmon smolts has been estimated at 75%. For Tracy the corresponding estimate is 15%, the difference reflecting the larger volume of Clifton Court Forebay at the Banks Pumping Plant.

So, entrainment of salmon smolts and striped bass can be estimated from salvage as entrainment = salvage/screening efficiency/(1-prescreen mortality).

If estimates can be made for smelt for the two factors, screening (louver) efficiency and prescreen mortality, smelt salvage could be used to estimate entrainment and, therefore, entrainment mortality.

<u>Screening (louver) efficiency for delta smelt</u>

The Tracy Pumping Plant has both primary and secondary louvers. Smelt diverted by the first set of louvers are diverted a second time, into the salvage tanks, by the second set of louvers. Bowen estimated the efficiency of both sets of louvers for adult smelt (Bowen, personal communication). The efficiency (fraction of fish diverted) of the first set is about 0.20, and the efficiency of the second set is about 0.75. The overall efficiency of both sets is about 0.15. According to Silva (Ron Silva, Bureau of Reclamation, personal communication), the efficiency of the second set of louvers at Tracy should be comparable to the overall louver efficiency at the Banks Pumping Plant.

Therefore, louver efficiency could be assumed at about 0.15 for the Tracy Pumping Plant and about 0.75 for the Banks Pumping Plant. Both estimates are based on the work of Bowen, who raises cautions about the need to account for the uncertainty in any use made of the estimates.

<u>Prescreen mortality</u>

No estimates have been made of prescreen mortality of smelt at Banks or Tracy pumping plants. However, estimates of exponential adult mortality rate for the entire population can be made using the Kodiak Spring trawl data (Miller 2005a). These month-to-month estimates range from -0.009 to -0.062 with an average of -0.025/day.

This general, Delta-wide exponential mortality rate provides a starting point for estimating prescreen mortality. The average residence time for Clifton Court Forebay can be estimated using the volume of the forebay (30,000 acre-feet) and the pumping rate. Similarly, the volume of water where prescreen mortality occurs at Tracy can also be estimated. When combined with the Tracy export rate, average residence time can be estimated there.

Using residence time and the exponential mortality rate, the percentage mortality can be estimated, assuming that prescreen mortality is the same as mortality throughout the Delta. It is also possible that mortality is higher in Clifton Court Forebay and before the Tracy louvers than it is throughout the Delta. Therefore, provision must be made to reflect this possibility in estimates of adult entrainment mortality.

Estimating adult entrainment mortality

<u>From Salvage</u>
Beginning with adult salvage at each pumping plant, the number of smelt approaching the louvers can be estimated by dividing salvage by louver

efficiency. Then, prescreen residence time can be estimated from the export pumping rate and prescreen volume. Knowing the exponential mortality rate and residence time, the prescreen mortality fraction can be estimated. Dividing the number of smelt approaching the louvers by 1.0 minus this prescreen mortality rate estimates the number of smelt entrained and, therefore, because none of them survive the salvage process, the number of smelt suffering entrainment mortality.

Table 1 shows the estimates of entrainment under various assumptions of louver efficiency and prescreen exponential mortality rate. The Excel worksheet used to calculate these estimates is available and can be used to test the effect of various assumptions about louver efficiency and prescreen mortality. Send an email to bjmill@aol.com to obtain this worksheet.

The data in Table 1 indicates that entrainment estimates are relatively sensitive to assumptions about louver efficiency and relatively insensitive to assumptions about prescreen mortality.

<u>From smelt densities near the pumping plants</u>
Smelt entrainment can also be estimated by multiplying the densities of smelt at stations near the export pumps by the export rates. Densities, export rates, and resulting estimates of entrainment are in Table 2. Densities were estimated from the average catch per unit effort (CPUE) in the southeast Delta (see "Estimating areas and volumes of water in the region, San Pablo Bay to Stockton and Walnut Grove" for a definition of this

area) from the Kodiak Spring Trawl. These trawls have only been carried out beginning in 2002, so this method is not applicable to years before then.

Estimating adult percentage entrainment

<u>Estimates by two methods</u>

The population of adult smelt has been estimated using data from the Kodiak Spring trawls, carried out in 2002 through 2005 (Miller 2005a). For these four years, there is a good relationship between the adult population estimated by the Kodiak Trawl and the previous fall midwater trawl abundance index (Miller 2005b). Figure 2 shows this relationship. The Beverton-Holt-type curve was fit by hand by adjusting the two parameters in the equation shown on the figure. The relationship between these two estimates can be used to estimate the adult population from the fall midwater trawl abundance index in years before the Kodiak Trawls were carried out. Therefore, the percentage of the adult population entrained can be estimated by dividing the entrainment estimate by the population.

Table 3 shows estimates of percentage entrainment under various assumptions, based on salvage. Figure 3 shows adult percentage entrainment over the last 12 years based on different assumptions about louver efficiencies and prescreen mortality. Table 4 shows estimates based on Kodiak Trawl densities and export rate.
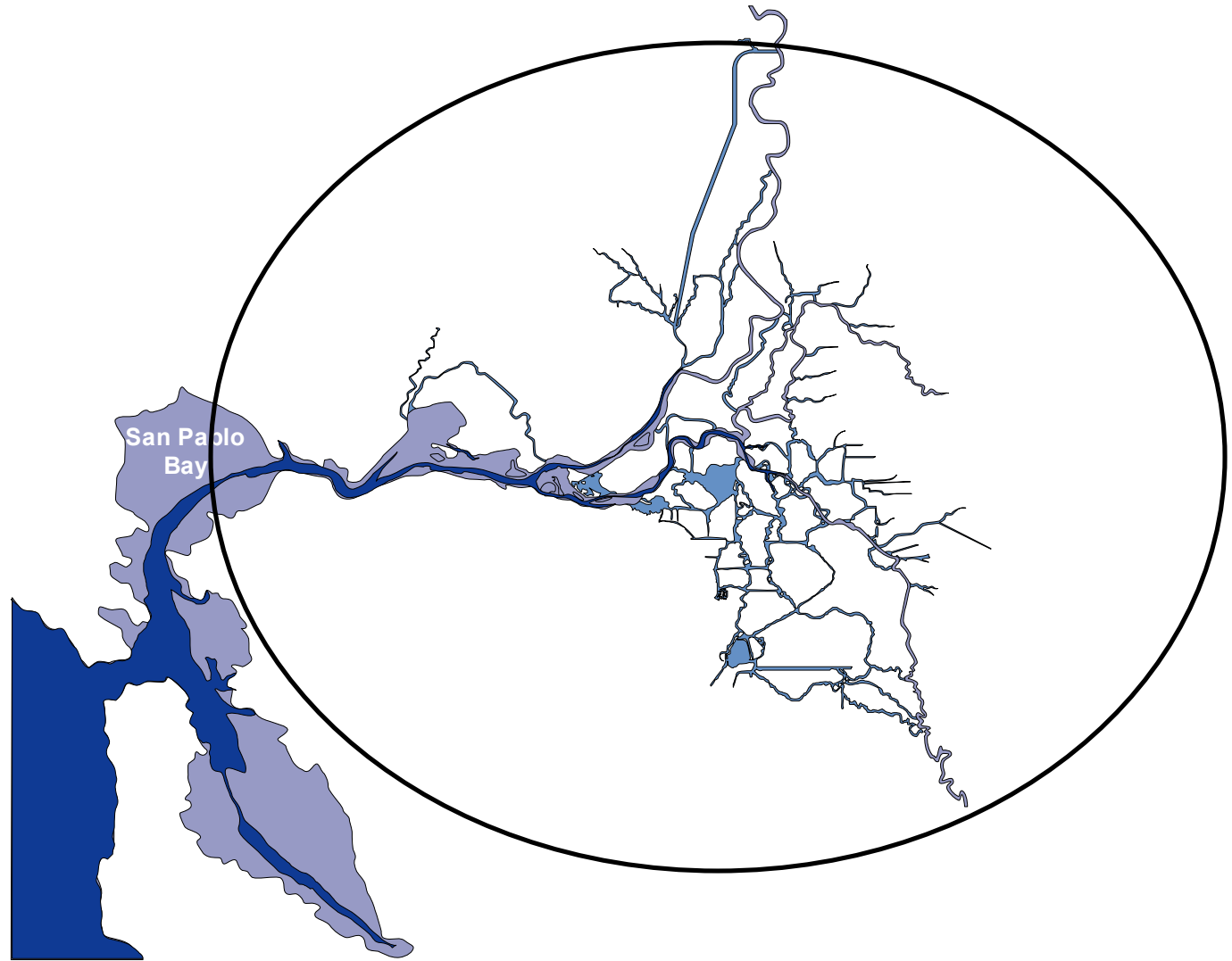
<u>Comparing the two methods</u>

Table 5 compares the two methods of estimating adult percentage entrainment for the years 2002 through 2005. The two methods do not produce comparable results. The reason for this can be seen from month-by-month comparisons of salvage and smelt densities near the export pumps. Significant salvage often occurs when densities near the pumps are zero, and little salvage sometimes occurs when densities are higher.

This comparison indicates that the method based on salvage is more reliable than the one based on smelt densities near the export pumps. After all, salvage data do, in fact, indicate that smelt have been entrained. Smelt densities near the export pumps may or may not be an indicator of entrainment.

Figure 1

Delta smelt habitat

San Pablo
Bay

Figure 2
February kodiak population of delta smelt vs. previous FMWT

Kodiak pop'n = (prev. FMWT)/(0.000118+prev. FMWT*0.00000105)

2001 FMWT

2003 FMWT

2002 FMWT

2004 FMWT

Y-axis: Kodiak February population

X-axis: previous FMWT
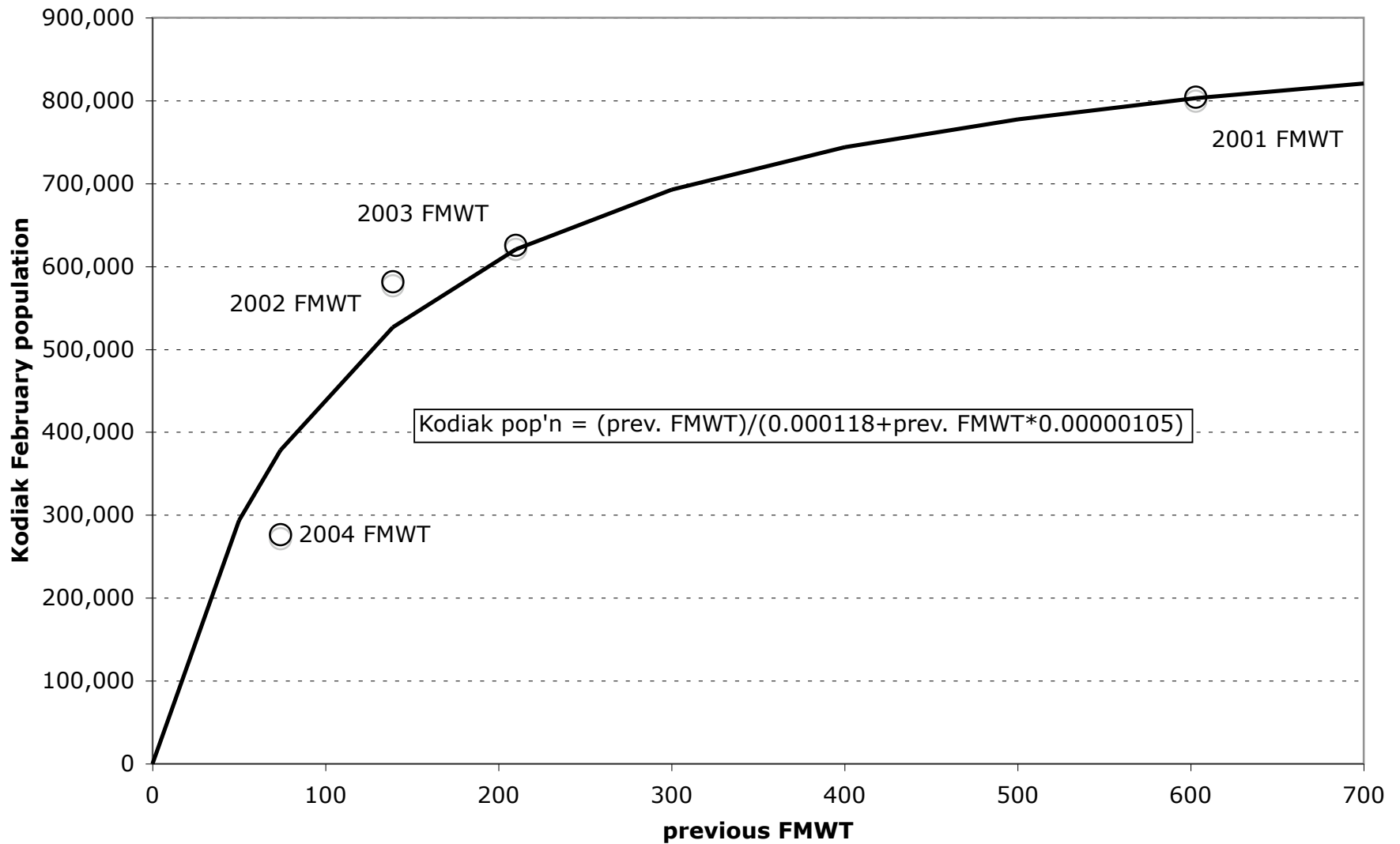
Figure 3
adult delta smelt percentage entrainment

Banks screening efficiency	0.75	0.25
Tracy screening efficiency	0.15	0.15
factor increase in exponential mortality rate at Banks	1	1
factor increase in exponential mortality rate at Tracy	1	1
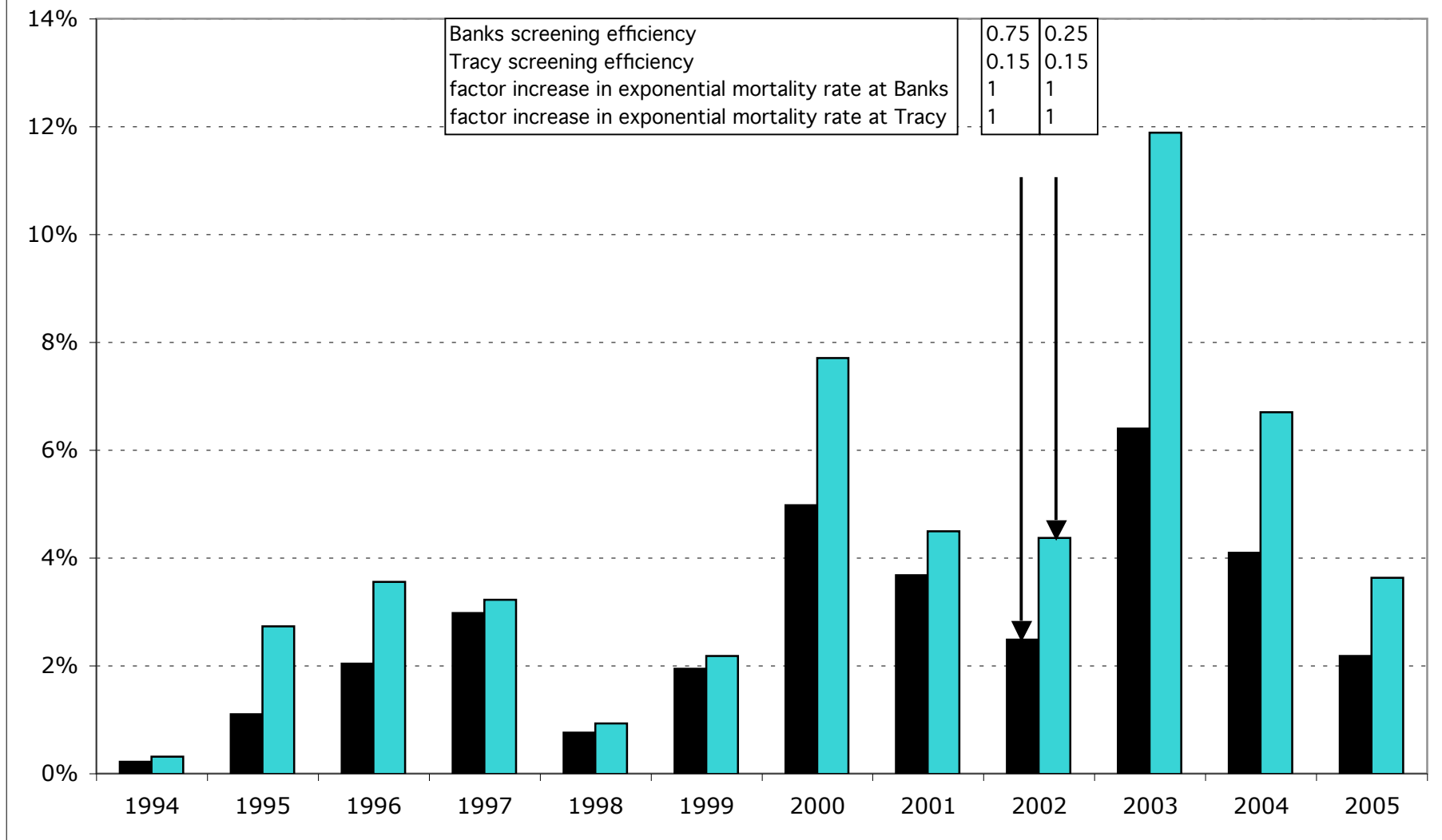
Table 1
adult entrainment mortality
sensitivity to screening efficiency and prescreen mortality

Banks screening efficiency	0.75	0.50	0.25	0.75	0.75	0.75	0.75
Tracy screening efficiency	0.15	0.15	0.15	0.10	0.15	0.15	0.15
factor increase in exponential mortality rate at Banks	1	1	1	1	2	3	4
factor increase in exponential mortality rate at Tracy	1	1	1	1	2	3	4
year	adult entrainment	adult entrainment	adult entrainment	adult entrainment	adult entrainment	adult entrainment	adult entrainment
1994	1,906	2,098	2,676	2,666	2,038	2,225	2,494
1995	4,942	6,773	12,265	5,582	5,451	6,226	7,916
1996	17,348	20,562	30,202	22,809	18,512	19,915	21,616
1997	15,184	15,495	16,427	22,465	15,460	15,864	16,456
1998	5,206	5,502	6,390	7,514	5,305	5,422	5,562
1999	14,570	15,009	16,326	21,416	15,134	16,238	18,497
2000	41,787	47,519	64,714	56,950	43,192	44,780	46,579
2001	30,507	32,198	37,271	44,069	31,071	31,728	32,493
2002	19,864	23,635	34,949	26,025	20,829	21,919	23,151
2003	37,112	45,067	68,932	47,714	39,490	42,232	45,395
2004	25,810	29,910	42,212	34,614	26,771	27,844	29,042
2005	6,104	7,116	10,152	8,144	6,334	6,591	6,878

month	year	adult smelt density, SE Delta #/AF	total exports AF	entrainment = density*export rate
Jan	2002	0.486	652,394	316,896
Feb	2002	0.000	476,528	0
Mar	2002	0.000	496,705	0
Apr	2002		253,385	
May	2002		94,317	
Jan	2003		616,879	
Feb	2003	0.078	591,898	46,259
Mar	2003	0.000	649,960	0
Apr	2003	0.000	266,428	0
May	2003	0.000	150,508	0
Jan	2004	0.233	687,857	160,585
Feb	2004	0.000	596,789	0
Mar	2004	0.000	678,126	0
Apr	2004	0.000	243,851	0
May	2004	0.000	105,400	0
Jan	2005	0.000	737,180	0
Feb	2005	0.000	492,419	0
Mar	2005	0.000	429,686	0
Apr	2005	0.000	349,148	0
May	2005	0.000	189,673	0

Table 2
adult delta smelt entrainment estimated from Kodiak Trawl densities and export rate

Table 3 adult percentage entrainment mortality sensitivity to screening efficiency and prescreen mortality							
Banks screening efficiency	0.75	0.50	0.25	0.75	0.75	0.75	0.75
Tracy screening efficiency	0.15	0.15	0.15	0.10	0.15	0.15	0.15
factor increase in exponential mortality rate at Banks	1	1	1	1	2	3	4
factor increase in exponential mortality rate at Tracy	1	1	1	1	2	3	4
year	adult percentage entrainment	adult percentage entrainment	adult percentage entrainment	adult percentage entrainment	adult percentage entrainment	adult percentage entrainment	adult percentage entrainment
1994	0%	0%	0%	0%	0%	0%	0%
1995	1%	2%	3%	1%	1%	1%	2%
1996	2%	2%	4%	3%	2%	2%	3%
1997	3%	3%	3%	4%	3%	3%	3%
1998	1%	1%	1%	1%	1%	1%	1%
1999	2%	2%	2%	3%	2%	2%	2%
2000	5%	6%	8%	7%	5%	5%	6%
2001	4%	4%	4%	5%	4%	4%	4%
2002	2%	3%	4%	3%	3%	3%	3%
2003	6%	8%	12%	8%	7%	7%	8%
2004	4%	5%	7%	5%	4%	4%	5%
2005	2%	3%	4%	3%	2%	2%	2%

Table 4 adult percentage entrainment estimated from Kodiak density and export rate	
year	adult percentage entrainment
2002	46%
2003	8%
2004	20%
2005	0%

	Table 5 comparison of two methods of estimating adult delta smelt percentage entrainment	
year	adult percentage entrainment estimated from Kodiak densities and export rate	adult percentage entrainment estimated from salvage
2002	46%	2%
2003	8%	6%
2004	20%	4%
2005	0%	2%

References

Miller 2005a, Estimating the population of delta smelt using the Spring Kodiak trawl data, William J (BJ) Miller, November 20, 2005

Miller 2005b, Overview of smelt analyses: Relationships among abundance indices and other important factors, William J (BJ) Miller, November 20, 2005